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APPLICATION

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FOR

INPUTTING DATA

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BY

Christopher CHAPMAN
David L. SANDBACH
and
Anthony HARDIE-BICK

James C. Wray, Reg. No. 22,693
Meera P. Narasimhan, Reg. No. 40,252
1493 Chain Bridge Road
Suite 300
McLean, Virginia 22101
Tel: (703) 442-4800
Fax: (703) 448-7397

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Inputting Data

INS B1

Field of the Invention

INS B2 ~~The~~ present invention relates to an input apparatus for generating control signals for ~~a~~ computer.

Introduction to the Invention

The tasks performed by the operator of a computer have defined the devices through which input data is generated. In the case of a personal computer, a keyboard and a mouse are used.

Design and operation of computer peripherals maintains the difference between computers and other equipment such as radio, hi-fi and television. The requirement of a keyboard and mouse is becoming increasingly perceived as a major barrier to the wider use of computers in a much broader range of activities.

An example is the emergence of MP3 and other related audio compression standards. These provide high quality compression of audio data. Most radio stations around the world are now able to broadcast over the internet, in additional to their traditional location in the electromagnetic spectrum. Furthermore, it has become possible to store an entire CD collection on a low cost computer hard disk. However, the computer, in its present form, is not considered as a serious alternative to radio or hi-fi devices. A similar situation exists with video data. The preferred viewing device, except when editing, is a traditional television set.

Computers are increasingly capable of receiving and manipulating many different media types within a common, easily used, computer-generated environment. However, the method of supplying input to the

computer terminal has restricted the wider use of this technology. The keyboard and mouse are best operated at a desk, and this prevents computers from being considered as replacements for a broad range of conventional electronic equipment. As computer and internet technology develops, increasingly the restrictions placed upon it are in the way the user interacts with computers through an input device.

The digitisation of graphic design, video and film editing has led to the development of improved devices for interaction with image data. The most widely used of input devices in this context is the graphics tablet, which is operated in the manner of a pencil-with-paper. On a large graphics tablet, it is possible to provide an area having the function of a keyboard, and this may be operated to generate occasional text where this required.

In three-dimensional computer modelling, no single preferred peripheral device has emerged. Several systems are known, optimised for particular applications. An example of this is radio tracking, which provides three dimensions of position and three dimensions of rotation. In a virtual reality application, a radio receiver is fixed to a users head-mounted display, and the position information obtained by analysing data from a fixed transmitter is used to determine stereoscopic images for the users eyes. The images are updated so as to provide an appropriate view for the angle and position of the user's head. Similar devices may be used to track the position of a hand, including devices that use ultrasound to determine orientation. Hand gestures resulting from finger movement may be tracked using a data glove. However, none of these devices is suitable for replacing a keyboard or mouse due to the requirement to suspend the devices in space in order to generate position data in the third dimension.

Graphics tablets and three dimensional input devices may be suitable

for replacing the keyboard and mouse in certain applications. However, their high cost, and other practical considerations, make them unsuitable replacements for the widespread, low cost and ubiquitous keyboard and mouse of the personal computer.

Summary of the Invention

It is an aim of the present invention to provide an improved input apparatus for supplying control signals to a computer.

Brief Description of the Drawings

Figure 1 shows a sensor and a computer terminal;

Figures 2 and *3* detail construction of the sensor shown in *Figure 1*, including microphones and a sensor core;

Figure 4 details components of the sensor core shown in *Figure 3*, including analogue to digital converters, orientation sensors and a digital signal processor;

Figure 5 details the digital signal processor shown in *Figure 4*;

Figure 6 details one of the analogue to digital converters shown in *Figure 4*;

Figure 7 details a frequency domain analysis of audio data recorded from one of the microphones shown in *Figure 2*, in response to a first type of touch event;

Figure 8 details a time domain analysis of audio data recorded from two of the microphones shown in *Figure 2*, in response to a second type of touch event;

Figure 9 details steps executed on the digital signal processor shown in *Figure 4*, including a step of identifying a drag position, a step of identifying

a hit position and a step of identifying sphere orientation;

Figure 10 details the step of identifying a drag position shown in *Figure 9*, including a step of correlating with templates and a step of identifying intersecting arcs;

Figure 11 details templates that are used in the step of correlating with templates shown in *Figure 10*;

Figure 12 illustrates the step of identifying intersecting arcs shown in *Figure 10*;

Figure 13 details the step of identifying a hit position shown in *Figure 9*;

Figure 14 details the orientation sensors shown in *Figure 4*, including a magnetic field sensor and a gravitational field sensor;

Figures 15 and *16* detail the magnetic field sensor shown in *Figure 14*;

Figures 17 and *18* detail the gravitational field sensor shown in *Figure 14*;

Figure 19 details the step of identifying sphere orientation shown in *Figure 9*;

Figures 20 and *21* detail construction of a charger and receiver unit for use with the sensor and computer terminal shown in *Figure 1*;

Figure 22 details components of the computer terminal shown in *Figure 1*, including a memory;

Figure 23 details contents of the computer memory shown in *Figure 22*;

Figure 24 summarises steps performed by the computer terminal shown in *Figure 1*, including a step of calibrating the sensor and a step of using the sensor;

Figure 25 details the step of calibrating the sensor shown in *Figure 24*;

Figure 26 details the step of using the sensor shown in *Figure 24*, including a step of processing touch event data; and

Figure 27 details the step of processing touch event data shown in *Figure 26*.

Detailed Description of The Preferred Embodiments

A computer terminal is illustrated in *Figure 1*. The computer terminal **101** comprises a high resolution display panel **102** and standard personal computer circuitry. The display **102** is the only visible part of the computer. The components of the computer are built in to the display housing. The computer is connected to the internet, and provides access to media of many different types, including audio, video, applications such as word processors, and so on. This highly varied functionality is provided by the combination of an internet browser software application and a graphical user interface environment such as X-Windows. This combination of technologies, both hardware and software, with information presented through a graphical display, may be considered as a first kind of computer generated environment. A second kind of computer generated environment is one in which a three dimensional virtual world is presented on a two dimensional screen, and various forms of user input enable the user to navigate, as if physically present, in the virtual space. Virtual spaces of this type are presently used widely in games, but also for serious business applications, such as the representation of bug tracking in complex computer software development. Three dimensional virtual worlds are widely believed to be the future of the Internet, though at the present time, specific interpretations of this vision have not been sufficiently developed to provide practical engineering proposals.

In order to interact with a computer generated environment, a user must have convenient control over the position and orientation of their viewpoint. In the case of a conventional computer desktop environment, navigation involves convenient movement of a cursor or pointer **103**. Furthermore, text entry is required also. The amount of text entry required depends upon the application, but these two requirements, movement and text input, can be seen as fundamental to any general purpose computer environment, of any type.

The present day windows-based desktop environment was developed over many decades, and has evolved as a result of the availability of the mouse, along with a keyboard for text entry. At the time of their development, windows and mouse -based graphical user interface environments were not considered stressful to use. However, their use on every desktop, and near constant use daily in the workplace, has resulted in various stress-related symptoms, including Repetitive Strain Injury (RSI) and Carpal Tunnel Syndrome. That these injuries exist indicates that the conventional computer interface is at least mildly stressful to use, and that better methods of input will enable worker productivity to be increased as well as potentially opening up general purpose computers to increased daily use in non-stressful leisure-related activities.

An improved computer input device is shown in *Figure 1*. The computer input device **104** is spherical in shape. The sphere is approximately six centimetres in diameter. Usually, the sphere **104** is supported in the left hand, as shown, while a finger of the right hand traces across its surface in order to affect and control the position of the pointer **103** on the screen. The sphere **104** may be freely oriented in any degree, and movements of the finger are interpreted as being made with respect to

the screen **102**, rather than locally with respect to the surface of the sphere **104**. In this way, the user can freely rotate and orient the sphere, while performing finger-movements on any part of its surface, which may then be interpreted as being performed in the space of the computer-generated environment, rather than in the physical environment of the input device **104** itself. This removes a layer of abstraction from the computer interface, and enables a language of interactions to be developed that is inherently intuitive and fast.

In a two-dimensional desktop environment, the sphere presents an infinite surface over which the mouse pointer may be moved, thus mimicking mouse movements, but accomplished entirely with movements of the fingers, and including rotations of the sphere, or ball, **104**, by the left hand when necessary.

Deliberate movements of a finger across the surface are interpreted as a movement of the pointer in the computer-generated environment. Manipulations of the left hand generate touch event signals that can be ignored. The tracing of a finger across the surface of the sensor **104** is a first method of generating input data. Using a traditional computer mouse, a click or double click is used to signify an action that is performed with respect to the location of the pointer on the screen **102**. This is achieved by a tap or double tap on the sensor **104**, regarded as a hit. The position of the hit may be used to determine the nature of the command to be performed. However, a far wider variety of events is possible with the sphere **104**.

The sphere **104** may be used to enter text characters. To signify a change from the previously described method of graphical operation, the sensor is hit, fairly hard, anywhere on its surface. Thereafter, movements of a finger on the surface may be interpreted as alphanumeric characters.

Text entry may be performed one character at a time, using character recognition. Alternatively, for high speed text entry, a form of shorthand writing may be used.

The sphere **104** has a slightly roughened surface. Friction between a finger and the surface, as the fingertip is moved across it, results in the generation of random acoustic noise. The friction-generated noise is analysed in order to determine the position of a finger-drag event of this type. The arrangement of microphone sensors to perform detection of noise generated in this way is shown in *Figure 2*. The shell of the sphere comprises three millimetre thick silicone rubber, and this is covered by a fine nylon felt that provides a suitable noise-generating surface. Directly beneath the silicone rubber shell, arranged equidistant from each other, are four microphones **201**, **202**, **203** and **204**. These have a frequency range substantially equal to that of human hearing, and can be general purpose audio microphones. Each microphone may be considered as being at the centre of a face of a three-sided pyramid, or regular tetrahedron. The angle made between any two microphones at the centre of the sphere is approximately one hundred and ten degrees.

Signals received by an individual microphone may be analysed to identify the proximity of a noise-generating drag event, and the results of an analysis of this type from two or more microphones are combined to identify the location of the touch event on the surface of the sphere.

Further details of the construction of the sphere **104** are shown in *Figure 3*. During manufacture, the silicone rubber shell is created in two halves **301** and **302**. A central core **303** contains the circuitry of the sensor. Between the core **303** and the silicone rubber shell is a layer of acoustically isolating and shock absorbant polyester fibre **304**. This construction firstly

ensures that microphones **201** to **204** are sufficiently acoustically isolated from each other, and that each microphone only receives sound directly from the silicone rubber shell. As a significant further advantage, however, this construction provides a very high level of shock-immunity, so that the sphere **104** may be handled extremely roughly without damage. The microphones **201** to **204** are embedded in moulded silicone rubber mountings in the shell itself.

The two halves **301** and **302** of the sphere **104** are combined using an acoustically homogeneous silicone rubber seal. The core **303** contains a rechargeable battery, and this must receive power externally when recharging is required. In order to avoid compromising the structural integrity of the surface by a wire connection, an inductive loop **305** provides contactless access to the recharging power source.

Circuitry contained within the central core **303** shown in *Figure 3* is detailed in *Figure 4*. A first stereo analogue to digital converter (A-D) **401** receives analogue audio signals from the first two microphones **201** and **202** a second stereo analogue to digital converter **402** receives analogue audio signals from the second two microphones **203** and **204**. A suitable analogue to digital converter is the CS53L32A, made by Cirrus Logic, available from http://www.cirrus.com. The converters **401** and **402** generate a multiplexed digital audio signal that is supplied to a digital signal processor (DSP) **403**. The digital signal processor is preferably a Motorola DSP56603, that includes arithmetic and memory circuitry suitable for audio signal analysis. Design data and other information about the DSP56603 is available from http://ebus.mot-sps.com.

Analysis of signals supplied to converters **401** and **402** results in touch event position signals being generated, and these are transmitted

digitally from a transmitter **404** to a receiver connected to the computer terminal 101. Positional signals are generated with respect to the terminal **101**, irrespective of any degree of rotation of the sensor **104**. This is facilitated by orientation sensors **405**. The signals from the orientation sensors define the orientation of the sphere **104** with respect to the screen **102**, and thereby enable calculations to be performed that effectively remove the orientation of the sphere from the interpretation of touch events made upon its surface. Said touch events are thereafter considered and interpreted with respect to the screen, regardless of the sphere's actual orientation. From the user's point of view, the sphere always looks and feels the same, and can rotate it and operate it without concern for its orientation.

In order to measure orientation of the sphere, the orientation sensors **405** characterise sensor orientation as a first rotation RM about a horizontal axis due to the Earth's magnetic field and a second rotation RG about a vertical axis due to the Earth's gravitational field. By combining these data items with data about the positions of touch events occurring on the surface of the sphere, it is possible to interpret user touch events on the sphere with reference to a standard space in which the computer terminal **101** is located. Thus, for example, a forward dragging movement of the finger towards the screen **101** will move the cursor upwards, regardless of the sphere orientation.

The core **303** includes a power management circuit **406**, that facilitates low power and shutdown modes for the DSP **403**, and other circuitry. The power manager **406** receives power from a rechargeable NiMH battery **407**, and also facilitates rectification and current regulation of recharging power supplied from the inductive loop **305**.

The digital signal processor **403** shown in *Figure 4* is detailed in *Figure 5*. Several data and address busses are present within the DSP, and these are summarised for the sake of clarity by a simplified wiring connection **501**. Timers **502** provide pulse width timing capabilities that are used to measure signals from the orientation sensors **405**. Input and output circuits (I/O) **503** provide several physical connections from the DSP to the other components in the core, including the A-D converters **401** and **402**. The program ROM and RAM **504** includes bootstrap instructions and control instructions for co-ordinating interface operations with other circuitry in the core **303**, and for performing real time signal analysis. An X data RAM and a Y data RAM **505** and **506** provide a pair of operands per instruction cycle to an arithmetic and logic unit (ALU) **507**. The ALU is thereby capable of fetching and multiplying two data operands from X and Y memory **505** and **506** in every instruction cycle. This arrangement facilitates efficient implementation of the processing algorithms that are required in order to determine the position of touch events on the surface of the sphere.

Each of the A-D circuits **401** and **402** comprise circuitry as shown in *Figure 6*. A first channel pre-amplifier **601** receives an unamplified audio signal from a microphone and increases its intensity to that which is suitable for digital to analogue conversion. An anti-alias filter **602** removes frequency components above half the sampling rate, so as to ensure that subsequent frequency analysis of audio data gives an accurate representation of the spectrum. The output from filter **602** is supplied to the left input of a stereo sixteen bit low power analogue to digital converter chip **603**. The sampling rate is 44.1kHz. Another channel is implemented for a second microphone using pre-amplifier **604** and anti-alias filter **605**. A

common multiplexed output is supplied from the A-D converter chip to the DSP **403**. Additional clock and word synchronisation signals have been omitted from this diagram for the sake of clarity.

An analysis of several seconds of audio data from a single channel is shown in *Figure 7*. The vertical axis represents time, and the vertical axis represents frequency. In this graph, the amplitude of a particular frequency component at a particular time is represented by density. The graph shows a plot of a signal that results from the movement of a finger across the surface of the sphere.

At the start of the plot **701** the fingertip is distant from the microphone. Sound waves reaching the microphone are primarily transverse waves, oscillating perpendicular to their direction of propagation. The silicone rubber filters high frequencies but has little effect on the low frequencies. Thus, the signal reaching the microphone, regardless of its actual amplitude, contains an indication of the distance due to the relative strengths of high and low frequencies. As the finger tip moves closer, higher frequencies increase, while the strength of the low ones remains substantially the same. As the fingertip becomes increasingly close to the microphone, at **703**, a completely new set of frequencies is added in the spectrum. This is due to longitudinal waves being transferred across the thickness of the silicone rubber from the fingertip, directly to the microphone. As the microphone is approached, there is a mixture of both longitudinal and transverse waves, as identified from the two distinct areas of the graph at **703** and **702**.

A final exceptional condition is reached when the fingertip is directly over the microphone. The high frequency components are generated by the friction between the edge of the finger and the roughened surface of the

sphere. However, when the finger is directly over the microphone, these high frequency components are masked, and the sound picked up by the microphone comes from the centre of an area of the fingertip alone. At **704**, a sudden loss of high frequencies occurs because these frequencies are damped by the area of the fingertip. The low frequencies exhibit a characteristic change, having a more balanced profile.

These changes provide a characteristic set of descriptions for finger dragging events that occur on the surface of the sphere. By comparing the outputs two or three channels at once, the position of a moving fingertip anywhere on the surface of the sphere **104** may be identified.

Hitting the sphere, to perform the equivalent of a mouse click, does not contain as much frequency data, and so a different type of analysis is used. The speed of transverse sound waves in the silicone rubber shell is in the order of only twenty metres per second. This makes it possible to discern a time difference for wavefronts arriving at different microphones. A pair of graphs resulting from a simultaneously digitised hit event are shown in *Figure 8*. Trace **801** is for the more distant microphone, and it can be seen that this commences a short period after the second trace **802**. The difference in initial characteristic wavefronts is in the order of two thousandths of a second. This provides a reasonably accurate source of position data. The traces **801** and **802** also exhibit differences in frequency content, which may be observed in the jaggedness of the second trace **802**, which is the microphone nearest to the hit event. Waveform **801** reaches a higher peak, due to the lack of damping provided by the finger over the point of impact just after the hit event has occurred. Several such characteristics may be analysed and the results combined so as to identify a touch event characteristic to an increased level of accuracy.

The main sequence of steps performed by the DSP **403** shown in *Figure 4* is summarised in the flow chart in *Figure 9*. At step **901** a frequency domain analysis is performed on each of the four channels of buffered audio data. At step **902** a question is asked as to whether a drag or a hit event has been observed in the data. It is possible that neither is identified, either due to lack of occurrence, or because a clear characteristic cannot be identified. If neither drag nor hit is present in the audio data, control is directed to step **905**. If a hit is observed, control is directed to step **904**, or, if a drag is observed, control is directed to step **903**. At step **903** the drag position is identified. At step **904** the hit position is identified.

At step **905** the sphere orientation is identified by analysing data from the orientation sensors **405**. At step **906** a question is asked as to whether any data needs to be transmitted to the computer. For example, if no touch event has occurred, and the orientation has not changed, no data need be transmitted, thus saving battery life. If no events occur over a prolonged period of time, say twenty seconds, the sensor can be placed in a power down mode. When held in either hand, even if not being used, the sensor will sense small changes in orientation, indicating that it is probably about to be used. If data is available for transmission, control is directed to step **907**, where data is transferred over a serial link from the DSP **403** to the radio transmitter **404**, for transmission to the computer **101**.

The step of identifying the drag position **903**, shown in *Figure 9*, is detailed in *Figure 10*. At step **1001** the four channels of buffered audio data are analysed to identify the three with the greatest amplitude. These three are the channels whose analysis will yield the most accurate touch event characterisation. The three loudest channels are called A, B and C. At step **1002** the first of these three channels is selected. At step **1003** a frequency

domain analysis is performed, and the results of this are normalised, such that the loudest frequency component has an amplitude of one. At step **1003** a correlation is performed with respect to a set of templates. Each template characterises a particular frequency response that is expected to occur at a known distance from a microphone. Thus, with reference to *Figure 7*, a template exists for the frequency characteristic at **701**, **702**, **703** and **704**. Each template has a different shape. The degree to which actual microphone data matches one of these templates indicates its proximity to the characteristic distance of that template.

A correlation score is generated as a result of step **1004**, and at step **1005** the two best scoring templates are selected. It is then known that the actual distance of the event from the microphone for that channel is between the characteristic distances of these two templates. At step **1006** the actual distance is identified by interpolating between the two characteristic distances, in proportion to the difference between the template scores. This identifies the characteristic distance for the channel, which may be DA, DB or DC, depending on which channel is being analysed. At step **1007** a question is asked as to whether there is another channel remaining to be analysed. If so, control is directed back to step **1002**. Alternatively, each distance DA, DB and DC will have been identified. At step **1008** intersecting arcs are identified across the surface of the sphere for each characteristic distance, and at step **1009** a point, P, is identified that is defined by the nearest point of convergence for the three arcs defined by DA, DB and DC.

The templates that are used in step **1004** in *Figure 10* are illustrated in *Figure 11*. Template **1101** corresponds to an ideal frequency response at a distance of D=40 mm away from a microphone. The signal at **701** in

Figure 7 would closely match this template. Template **1102** has a characteristic distance D=25 mm, and roughly corresponds to the plot at position **702** in *Figure 7*. Template **1103** has a characteristic distance D=10 mm, and would provide a high score for a signal occurring just after point **703** in *Figure 7*. Template **1104** corresponds to the fingertip being directly over the microphone, and corresponds to point **704** in *Figure 7*. By selecting the best two corresponding templates, the actual distance of the event from the microphone may be identified by interpolation between characteristic distances of the templates.

The distance of an event may be considered as a notional distance, as frequency characteristics may change for different finger sizes, applied pressure and other variable factors. Whatever the distances are, DA, DB and DC define three characteristic arcs, whose ideal convergence point P is illustrated in *Figure 12*. The ideal convergence point is the same regardless of these variable factors.

Identification of a hit position, shown at step **904** in *Figure 9*, is detailed in *Figure 13*. At step **1301** the three loudest channels A, B and C are identified. At step **1302** the first of these channels is selected for analysis. At step **1303** the signal is filtered. The filter removes frequencies below two hundred and fifty Hz, as this results in a better analysis being performed. Preferably an FIR linear phase filter is used. However, an IIR filter, such as that used to generate the trace shown in *Figure 8*, is acceptable, with a slightly reduced accuracy of results. At step **1304** an event start time is identified by analysing the channel data. At step **1305** a question is asked as to whether another channel remains to be analysed, and if so, control is directed back to step **1302**. Alternatively, start times will have been identified for each of channels A, B and C, and control is

directed to step **1306**.

The difference between start times for a pair of channels identifies a distance from the mid point between two microphones. On the surface of the sphere, this mid point is expressed as a line. At step **1306** distances are identified for each combination of start times, resulting in three lines, or arcs, being identified across the surface of the sphere. At step **1307** a characteristic common point is identified, in a similar manner to that shown in *Figure 12*. In theory, two such arcs are required. However, three are used to improve accuracy. Four may be used, if the channel data for all four microphones is of sufficiently high quality.

The invention provides a method of generating positional information by analysing the noise generated by friction between an object and a surface. Preferably the friction is generated by the movement of a finger across a surface. The surface may be flat, or curved, regularly or irregularly, or spherical. The surface may be elastic, temporarily or permanently deformable under finger pressure, or rigid. The invention includes any kind of interaction between a user's fingers and any such surface where resulting sounds are analysed to generate position information for a computer-generated environment. Position information generated in this way may be combined with information that defines the orientation of the surface with the projection upon a display device of a computer generated environment. This combination of position and orientation information enables sound-generating touch events made upon the surface to be interpreted with respect to a computer environment, irrespective of the orientation of the surface.

Orientation of the sensor is defined by rotations RM and RG about Earth's magnetic and gravitational fields. Detail of the orientation sensors

405 shown in *Figure 4* is shown in *Figure 14*. A magnetic field sensor **1401** and a gravity field sensor **1402** generate digital oscillation signals whose periods are measured in order to ascertain orientations within respective fields. A multiplexer and counter circuit **1403** provides interfacing and control signals for the oscillating circuits, and divides the frequencies down by an amount suitable for highly accurate measurement by the timers **502** in the DSP **403**.

The magnetic field sensor **1401** is detailed in *Figures 15* and *16*. *Figure 15* shows three mutually orthogonal inductors. Each inductor is less than ten millimetres long. *Figure 16* details a circuit suitable for detecting the polarity and magnitude of the Earth's magnetic field with respect to each of the three inductors. A logic gate **1601** provides a positive or negative DC bias via resistor **1602** to the presently selected inductor **1501** to **1503**. Selection of an inductor is provided by logical control signals supplied to tri-state logic buffers **1602**, **1603** and **1604**. An operational amplifier **1605** provides amplification for sustaining oscillations whose frequency is determined by the inductance of the selected inductor **1501** to **1503**. The DC bias provided by resistor **1602** drives the core of the selected inductor to near saturation.

Near to saturation, a coil's inductance changes in response to the applied field, even though the coil's windings and core are fixed. The additional offset towards or away from saturation, resulting from the Earth's magnetic field, may be detected in this way. By switching polarity of the DC bias in the coil, it is possible to determine the polarity of the Earth's magnetic field when different resulting oscillation frequencies are compared. If there is no difference, this indicates that the coil is aligned orthogonally to the Earth's magnetic field. The output from the operational

amplifier **1605** is supplied as a logic signal to the counter **1403**, and the DSP **403** determines the precise frequency of oscillation for each of the coils, in each polarity, and thereby the alignment, in three dimensions, of magnetic North. The circuit requires a couple of milliamps of current to operate, and the sensors are extremely small and of low cost. A suitable inductor, of the type shown in *Figure 15*, is the SEN-M magneto-inductive sensor, available from Precision Navigation of Menlo Park, California. Use of partly saturating inductors to detect the Earth's magnetic field in this way is detailed in United States patent 4,851,775.

The gravity field sensor **1402**, shown in *Figure 14*, is detailed in *Figures 17* and *18*. An enclosed spherical container is half filled with a liquid having a substantially different relative permeability to that of free space, at a frequency of around five hundred kHz. A suitable liquid is mercury, which has a relative permeability of around 0.7 at this frequency. Three coils **1702**, **1703** and **1704** are wound in close proximity to the container **1701**, and are mutually orthogonal. Each coil is connected in an oscillator circuit as shown in *Figure 18*. Each coil forms the inductive part of a tuned circuit, that also comprises two capacitors. A logical HCMOS NOR gate **1801** to **1803** provides amplification and a selection input to activate the oscillator circuits separately. The outputs from the oscillators are combined in a three-input NOR gate **1804**, so that an inductor selected for oscillation by a logical high input to gate **1801**, **1802** or **1803**, has its characteristic frequency presented as a square wave at the output of gate **1804**. The output from gate **1804** is supplied to the counter circuit **1403**. The frequencies of oscillation of the three coils depend upon the amount of immediately adjacent mercury. The three frequencies are measured in the DSP 403, and interpolated look-up tables are used to determine the actual

orientation of the sensor with respect to the Earth's gravitational field. The circuit of *Figure 18* requires less than one milliamp to operate.

The three-dimensional vectors for magnetic and gravitational ambient fields may be represented as two rotations of the sphere, RM and RG, about the magnetic North axis, and about the vertical gravitational axis.

The process of identifying RM and RG combines measurements from both the gravitational and magnetic field sensors. It is possible for either to experience interference, and the gravitational field sensor **1402** may experience instability due to motion of the mercury in the container **1701**, particularly if the sensor is moved about rapidly. The step of identifying the orientation of the sphere **905**, shown in *Figure 9*, is detailed in *Figure 19*. At step **1901** the rotation about magnetic North, RM, is identified. At step **1902** Kalman filtering is applied to the value of RM. A Kalman filter determines a measure of confidence in the current measurement, and increases low pass filtering when this confidence value is low. At step **1903** the rotation RG of the sphere about the vertical axis due to gravity is determined, and at step 1904 Kalman filtering is also applied to this value. At step **1905**, filtered values for RM and RG are stored for later transmission to the computer **101** when necessary.

In an alternative embodiment the Earth's magnetic field can be detected using silicon sensors employing the giant magneto-resistive effect. In a further alternative embodiment the Earth's gravitational field can be detected using accelerometers, which are more expensive, but facilitate detection of rapid acceleration of the ball **104**, which may be used as a further source of gestural information for navigating a computer environment.

After an extended period of use, the battery **407** requires recharging.

In order to recharge, the inductive loop **305** must be placed in an adjacent position to another matching inductive loop that is supplied by a 1kHz power source. This may be located in a charging unit as illustrated in *Figure 20*. The outside of the sphere has a mark directly opposite the location of the inductive loop **305**, and this mark must be uppermost when the sphere is placed on the recharging unit **2001**. The recharger **2001** may also conveniently double as the receiver for the data from the transmitter circuit **404**, and a serial connection **2002** provides the connection for this data to the computer terminal **101**.

Details of the charger and receiver unit **2001** are shown in *Figure 21*. An inductive loop and oscillator **2101** supply an alternating magnetic field to the inductive loop **305** in the sensor **104** during recharging. During use, the sensor **104** transmits radio signals to a radio receiver **2102**. A central processing unit (CPU) **2103** provides error correction of data received over the radio link. A universal serial bus (USB) interface **2104** provides a connection to the computer terminal **101** via the serial cable **2002**.

The computer terminal **101** shown in *Figure 1* is detailed in *Figure 2*. A central processing unit (CPU) **2203** provides co-ordination and processing for the terminal **101**. Instructions and data for the CPU **2203** are stored in main memory **2204**, and a hard disk storage unit **2205** facilitates non-volatile storage of data and several software applications. A modem **2206** provides a connection to the internet. A universal serial bus (USB) interface **2207** facilitates connection to the charger and receiver unit **2001**. Touch event and orientation data are received from the sphere **104** via the USB interface **2207**. A graphical processor **2208** provides dedicated graphics rendering capabilities to speed up the display of high resolution graphical images on the display **102**. An audio processor **2209** supplies

audio signals to loudspeakers in the computer terminal **101**, and receives audio signals from a microphone **2211**.

The contents of the main memory **2204** shown in *Figure 22* are detailed in *Figure 23*. An operating system provides common functionality for software applications **2302**. A device driver **2303** for the sensor **104** is also stored in main memory **2204** while the computer terminal **101** is switched on. The sequence of operations necessary to operate the sensor **104** is detailed in *Figure 24*. At step **2401** the sensor **104** is charged using the charger and receiver unit **2001** shown in *Figures 20* and *21*. At step **2402** the sensor is calibrated. In order to use the sensor, it is necessary to store orientation data so that the device driver **2303** is able to determine which way is forward, backwards, left and right with respect to the Earth's magnetic field, and therefore also substantially with respect to the terminal **101**.

It is assumed herein that orientation of the sensor within the Earth's magnetic and gravitational fields effectively provides orientation with respect to the terminal **101**. Clearly this would be untrue if the user operated the sensor from behind the terminal. However, for the purposes of practically operating the sensor, it may be assumed that touch gestures on the surface of the sphere **104** that are made with respect to the Earth's magnetic and gravitational fields are also made with respect to the location of the computer terminal **101**. If the terminal position is changed substantially, it will be necessary to perform the calibration at step **2402** again. At step **2403** the sensor **104** is used, and at step **2404** the sensor **104** is recharged. The design of the charger and receiver unit **2001** is such that the sensor **104** may be conveniently left at rest on the charger **2001** whenever it is not in use.

The step of calibrating the sensor **2402**, shown in *Figure 24*, is detailed in *Figure 25*. At step **2501** the computer requests the user to drag their finger from the back to the front of the sensor, moving over the middle of the top. After this is done, the computer requests the user to drag from left to right in the same fashion. Although both are not strictly necessary, this reduces the error in calibration. At step **2502** the orientation data from the sphere **104** is analysed in order to determine a user orientation angle AG, about the vertical axis of the Earth's gravitational field.

The step of using the sensor **2403**, shown in *Figure 24*, is detailed in *Figure 26*. At step **2601** touch event and or orientation data is received from the sensor **104**. This includes the angles of rotation RM and RG about the Earth's magnetic and gravitational fields. At step **2602** the user orientation angle AG calculated at step **2502** in *Figure 25* is subtracted from the sphere rotation angle RG in order to obtain a rotation value SG. At step **2603** a question is asked as to whether a touch event has been received. If not, control is directed to step **2606**. Alternatively, control is directed to step **2604**. At step **2604** the sphere co-ordinates of the touch event are rotated in opposite and equal degree to SG and RM, resulting in touch event data that has a stationary co-ordinate system, irrespective of the orientation of the sphere. At step **2605** the resulting touch event data is processed. Finally, at step **2606** the terminal-oriented data is supplied to the operating system **2301** via the device driver **2303**, for use by applications **2302**.

The step of processing touch event data **2605**, shown in *Figure 26*, is detailed in *Figure 27*. At step **2701** a question is asked as to whether a large hit has been received. A large hit is one where audio data from all four microphone channels is extremely loud, indicating the user has hit the sensor quite hard, request a change of mode. If a large hit is received,

control is directed to step **2702** where the current mode is swapped. Alternatively, if a large hit is not identified at step **2701**, control is directed to step **2703**. At step **2703** a question is asked as to whether the currently selected mode for the sensor is graphics mode or text mode. If text mode is selected, control is directed to step **2706**. Alternatively, graphics mode is identified, and control is directed to step **2704**. At step **2704** any small hits are interpreted as the equivalent of mouse button clicks. Finger drag events are used to modify the X and Y co-ordinates of the cursor. At step **2705** the cursor position is updated.

When used in text mode, control is directed from step **2703** to step **2706**. At step **2706** any small hits are interpreted as the equivalent of CAPS, CTRL and SHIFT events on a conventional keyboard. At step **2707** touch movements on the surface of the sphere are interpreted as character entry events. Alternatively, for high speed text entry, a form of shorthand can be used.

In an alternative embodiment, the DSP **403** performs data compression of audio signals from the microphones **201** to **204**. The compressed audio data is combined with orientation data, and is transmitted to the computer terminal **101** for analysis to determine surface event characteristics.

In the embodiments described above, the sensor is a passive device, requiring a sound to be made by a touch event on the surface of the sphere. In an alternative embodiment, an active sensor is provided. Sound may be injected into the surface of the sphere, and a surface pressure map may be constructed from sound characteristics that result from interference and reflection. If the sensor shell is made of a hard material, ultrasonic sound may be used to generate a highly detailed pressure map. The

pressure data may be used to facilitate additional methods of data entry. An alternative method of detecting pressure is the use of multiplexed pressure sensitive electrical sensors, whose conductivity changes in accordance with the applied pressure.

In a further alternative embodiment, touch events are detected by an electrical sensor in which capacitance of electrical conductors, near or embedded in the sphere's surface, is modified by the presence of parts of a hand or finger.

The spherical shape of the sensor facilitates rotation in any degree without this making any difference to the appearance or feel presented to the user. Touch events on the surface are made with respect to the computer display **102**. This has the psychological effect of extending the computer generated environment out into the space between the user and the terminal.

Although in the preferred embodiment the entire surface of the sphere is touch sensitive, it is possible that, for the purpose of providing a direct electrical connection during recharging, that a different embodiment may include an insignificant portion of its surface where touch sensing is not fully provided. Also, in certain embodiments, the spherical shape may be distorted, as a result of squeezing or due to a preferred distorted shape.

The sphere, being the simplest of three dimensional shapes, provides a suitable shape for universal object mapping. A complex shape, such as a telephone handset, may have its surface mapped to the surface of the spherical sensor **104**, and interaction with the handset, for example to dial a number, may be effected via interactions with the sphere. Alternatively, the shape of a three-dimensional object mapped in such a way may be modified using the touch events on the sensor's surface. The

shape, then changed, is remapped to the surface of the sphere, so that additional changes may be made. The universal shape of the sphere lends itself to interaction with a rich variety of complex shapes and forms.